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TECHNIQUES FOR EARLY CHARACTERIZATION OF BURN INJURIES
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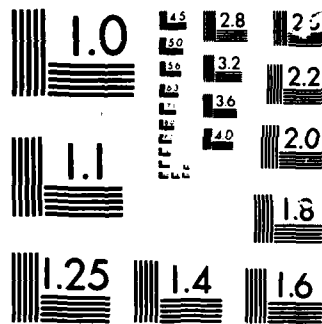
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TECHNIQUES FOR EARLY CHARACTERIZATION OF
BURN INJURIES

ANNUAL PROGRESS REPORT

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December 28, 1983

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Statement of the Problem

The problem addressed by the research reported on herein is concerned with the development and testing of two different non-invasive instruments for the early characterization of burns. An electro-optic burn depth indicator developed by the author quantitatively measures the red, green, and infrared reflectivity of a burn. We proposed to test this instrument on burns during the first few days post-burn, and determine whether this instrument has value in diagnosing burn depth when used in that time frame.

The second aspect of our program is concerned with developing a new instrument, the 20 MHz pulsed Doppler ultrasound skin blood flow indicator. This instrument was designed to detect and measure the characteristics of skin blood flow as a function of depth below the surface of a burn wound. It is expected that this information can be used to evaluate zones of stasis and predict eventual burn wound healing.

The research is directed toward the development of inexpensive portable instruments which can be used as aides in determining burn depth and estimating "time to healing" and are intended to be used as diagnostic tools to help characterize burn wounds, select the appropriate treatment modality, and to monitor healing processes.

Background

It has been shown in previous work that the time required for a burn wound to heal (i.e., less than or greater than three weeks healing time) is strongly correlated with the optical reflection properties of the wound when measured quantitatively between three and seven days post-burn. In our instrument, red, green, and near infrared light is focused on a small selected area of the burn wound, and the reflected intensities are measured automatically. Ratios of the reflected intensities (red to infrared, and green to infrared) are derived electronically and displayed. When these data are plotted on a graph as shown in Figure 1, we find that points representing measurements made on burns that eventually heal in less than three weeks (x's) generally fall above the dividing line shown on the figure. Points representing measurements on burns that require grafting, or on burns that take longer than three weeks to heal (o's) generally fall below the dividing line.

Several parameters may affect the accuracy of this correlation. These parameters include the age and sex of the patient, the location, etiology and extent of burn, presence of blood (denatured or not), number of days post-burn, etc. Our goal is to determine how these parameters affect the optical properties of the burn, and whether accurate predictions of burn depth or "time to healing" can be made within the first few days post-burn, using the electro-optic burn depth indicator.

The second approach to burn characterization involves the detection and measurement of the minute flow of blood in the intact capillary loops, and arteriolar and venous plexi which remain after the burn injury. This flow can be detected by means of the Doppler shift of 20 MHz ultrasound waves which we direct at small areas of the skin by means of a tiny transducer, and which reflect from the blood cells moving through the vascular system of the tissue. The injured tissue can be probed at different levels below the surface with a

depth resolution of approximately 0.3 mm. The characteristics of the blood flow at each level can be measured. This information is expected to correlate very well with the eventual healing pattern of the burn wound.

Approach

Our approach involves a five year plan of research, instrument development, clinical tests, and analysis. The first year of this project was devoted to:

- 1) Clinical tests on the electro-optic burn depth instrument, conducted at the Burn Center of Harborview Medical Center under the direction of Dr. David Heimbach, Director of the Burn Center, and Dr. Loren Engrav, Department of Surgery. The purpose was to start to accumulate a large data base so that we could correlate the optical properties of burns with the various parameters mentioned above;
- 2) Design and construction of the 20 MHz Doppler ultrasound instrument;
- 3) Initial characterization of the ultrasound instrument and modifications based upon our experience with it.

During the second year of this project, our efforts included:

- 1) Continuation of the clinical tests on the electro-optic burn depth instrument, conducted at the Burn Center of Harborview Medical Center. A total of more than 75 patients were included in our study.
- 2) Analysis of the data obtained with the electro-optic burn depth instrument for several categories of burns.
- 3) Tests of the ultrasound skin blood flow instrument on normal skin at one particular body location (finger pad).
- 4) Analysis of the information present in the Doppler spectrum of the ultrasound instrument, and identification of specific features of the spectrum with microvascular structures in the skin, as well as blood flow characteristics.

The third year of this study was devoted to:

- 1) A complete statistical analysis of the effectiveness of the electro-optic burn depth instrument as a predictor of "time to healing."
- 2) Design of a new transducer to be used with the ultrasound skin blood flow instrument.
- 3) A series of experiments with the ultrasound unit, measuring skin blood flow on normal subjects on a variety of sites.
- 4) Comparison of the ultrasound skin blood flow method with data taken simultaneously with a laser Doppler blood flow instrument.
- 5) Development of a workable patient protocol for measuring skin blood flow on burn patients at Harborview Burn Center, using the ultrasound skin blood flow instrument.

The results of our work during the third year of this program will be discussed below.

Succeeding years of this project will be devoted to a clinical test of the ultrasound skin blood flow instrument as a predictor of burn depth, and the design and construction of self-contained, compact instruments with simple output indicators for ultimate use by inexperienced personnel as aides in diagnosing burn injuries and selecting appropriate treatment.

Part I: The Electro-Optic Burn Depth Instrument

Introduction

In a study to determine the accuracy of our electro-optic device in predicting burn wound healing, over 80 patients were examined at the Harborview Burn Center, Seattle, Washington. Multiple skin sites on each patient were examined on successive days after injury with the Burn Depth Indicator (BDI), a device which measures the reflected intensities of three spectral regions of light. Red, green, and infrared light-emitting diodes (peaks at 550, 640, and 880 nm) were sequentially pulsed and the reflected intensities from the wound were measured and displayed in the form of ratios, red divided by infrared (R/IR) and green divided by infrared (G/IR). Along with the reflectance ratios, the final clinical outcome of each site was recorded either as the number of days to healing (complete re-epithelization) or as a surgeon's clinical observation, such as the time of burn excision. From this data, the burn sites were divided into two clinically important groups: healers, those which healed by themselves in 21 days or less; and non-healers, those which took longer to heal, or were deep enough to need excision of the injured skin and a graft. Other patient data were also recorded; age, sex, percentage of the body burned, body part of the site, etiology of the burn, and any medical complications.

In the preliminary studies, it had been shown that if the reflectance ratios were plotted against each other, the two burn-healing classifications occupied different regions of the plot. Healers generally fell in the upper left of a red/infrared versus green/infrared plot and non-healers fell lower and more toward the center. It was noted that one could graphically separate the groups with an empirically-drawn line and correctly classify the majority of the points. Clinically, one could then predict the time to healing of a new burn wound depending on where its measured reflectance ratios fell in relation to this line: above, indicating it would probably heal in 21 days or less; below, indicating a non-healer. In order to improve the device's performance, two questions needed to be investigated:

- 1) What is the "best" discriminant line separating the two healing classes?
- 2) To what extent is the device independent of the patient or wound state? In other words, does the user need to take account of other patient information in order to get the most accurate prediction?

There might, for example, be different discriminant lines for different burn locations on the body or for different burn etiologies. Using a statistical technique called logistic regression, we attempted to solve these two questions.

Statistics

Logistic regression was used to find both the "best" discriminant line for the healing classes using the reflectance data alone and also to investigate the possible correlation of other patient and wound variables to the healing outcomes. Logistic regression is a technique often used for analysis of studies with binary outcomes and its properties make it convenient for discriminant analysis. The essence of logistic regression is that one does not regress predictor variables (in our problem the reflectance ratios and other clinical data) directly against the response data (1 = healed, 0 = not healed), but does so through a transformation called the logit function,

$$p = \frac{e^Y}{1+e^Y}, \text{ where } p \text{ is the probability of healing and } Y \text{ is the predictor.}$$

With a binary result, one has the statistical problem that the response is constrained to be either a success or a failure, a '1' or a '0.' However, the variables being regressed against may also be qualitative, such as the sex of a patient or the body part of the burn, or they may be quantitative like the age of the patient, the reflectance ratios, or the percentage of the body burned and, therefore, continuous and unbounded. Thus, a linear predictor of these variables X_i , defined by

$$Y = \sum_i \beta_i X_i$$

is constrained to be continuous and unbounded. By using the logit function, one transforms the linear predictor, Y , into the probability of a success or a failure, so satisfying the constraints on the response. One way to look at the logistic regression is that one is first assessing the tolerance or robustness, Y , of the patient with certain clinical characteristics, X_i , and then using the logit function to transform this tolerance into a probability of a positive response. The greater the tolerance, the greater the probability of a successful outcome. In our example, certain reflectance ratios indicate a quick-healing or superficial burn (Y large) and so transform to a high probability of healing in under 21 days. If the patient has a negative tolerance, the probability is low that he will heal quickly ($p < 0.5$).

When one solves for the regression coefficients from a training set of responses, Z_j , and predictor variables, X_{ij} (like those collected at the Harborview Burn Center), one then has a model which can be used to predict the probability of healing for a new patient given his clinical information, X_{jk} .

For a discriminant analysis, logistic regression is convenient because, if the two response groups are approximately equal in number and contain no gross outliers, a good discriminant line is obtained by solving for the case of $p = 0.5$. This condition corresponds to $Y = 0$. Solving the linear model for R/IR in terms of G/IR and any other clinical data terms gives us a line that separates the R/IR vs. G/IR plots into two regions, one where points have a greater than 50% chance of healing before 21 days and another with probability less than 50%.

Linear Models

A predictor, Y , based on a linear model, $Y = \sum_i \beta_i X_i$ is transformed by the logit function into a probability of healing for a burn site. In doing the statistical

analysis, one is free to create any linear model one chooses to test a variable's correlation to healing. We knew we had at least two variables, the reflectance ratios, that were important in predicting burn healing and so all models included those two terms, $Y = \beta_0 + \beta_1(R/IR) + \beta_2(G/IR)$. The coefficients of this regression, when solved for $p = 0.5$, give the 50% line for the data set as a whole. Our next goal was to enlarge the model with terms representing other patient and wound information to see if they were helpful in predicting healing, and, if so, how they affected a discriminant line. Terms we wished to add to the minimal reflectance model were age, sex, body part, percentage of the body burned, and etiology. By adding these terms and checking their significance in a regression, we were able to examine the BDI's dependence on them. Increased fit, by using extra patient variables in addition to the reflectance ratios, would mean that better healing prediction would be possible if these terms were also used. By examining how different terms affect the 50% line, one could create a family of discriminant lines applicable to different patient or wound groups if necessary.

Estimation and Goodness of Fit

As binary response data does not conform to many of the assumptions necessary for least squares estimation, another technique called maximum likelihood estimation (MLE) is often used in logistic regression. Instead of choosing linear coefficients that minimize the mean-square error, MLE tries to choose coefficients that maximize the probability of the response data set, Z_j , given the predictor variable data set, X_{ij} . This is done by maximizing the likelihood or joint probability density function of the response variables, Z , by varying the linear coefficients, β_i . This can be done by iterative means if one knows the link function of the response variable (in the case binomial), the transformation of the link function relating the linear predictor, Y , to the response variables (the logit function), and the form of the linear model ($Y_j = \sum \beta_i X_{ij}$). The statistical package used for our analysis was GLIM (Generalized Linear Interactive Modeling) written by the Royal Statistical Society, Release 3, 1973. Using an iterative MLE algorithm, this package computes regression coefficients and their standard errors for user-specified linear models and link functions.

As a measurement of the goodness of fit of the current model to the data set, GLIM provides the user with the deviance and the degrees of freedom left after a fit. The deviance measures the error left in the data after the effects of the current model have been taken out. It is computed by comparing the maximum likelihoods of the current model and the full model, one that has as many terms as data points, giving a nearly perfect fit. The deviance will decrease as additional terms are added to a model as it approaches the full model. By observing the decrease in the deviance compared with the decrease in the number of degrees of freedom left in the data set, one can gauge the significance of the added terms to the regression. Large decreases in the deviance with the addition of only a few terms indicates a worthwhile addition to the model. As the addition of any term to the linear model will cause a reduction of the deviance, one must try to find the optimum model, keeping the number of terms low and being wary not to merely fit an arbitrary subgrouping of the data to its mean. The significance of a term can also be evaluated by looking at the relative size of the regression coefficient to its standard error. Large standard errors lead one to believe that no added fit is acquired by including that variable.

Results

The data was first examined and trimmed using MINITAB, a statistic and data management package. Histograms and scatter plots could be made of the reflectance

ratios and other patient data, in order to check for outliers and look for general trends in the data. Earlier studies had shown that the third day after injury was when the BDI was most accurate in healing predictions, as at this time the wound had finally stabilized and was no longer subject to severe edema. As BDI predictions on later days are of less value to a surgeon, in this analysis we only examined measurements taken on the third day after injury. Outliers in the reflectance ratio data and patients with medical complications were also trimmed from the data set. After these manipulations, 548 sites from 50 patients were left for the regression.

Results for a GLIM run are shown in Table 1.

Table 1 GLIM Logistic Regression Results

Model	Deviance	Degrees of Freedom	Variable Type
null	754	547	
R/IR+G/IR	618.2	545	continuous
" + Body Part	591.6	540	6 levels
" + Sex	594.5	544	2 levels
" + Age + (Age) ²	603	543	continuous
" + Percent Burned	607	544	continuous
" + Burn Etiology	592.8	542	4 levels

To the left is the model being tested and the other columns list the variables and degrees of freedom for that fit. The first fit was the null model when no predictor variables were included and all that was computed was the grand mean. The deviance here gives one a measurement of the raw scatter of the patient responses and shows the maximum deviance one can have (it is the farthest model from the full model).

Next listed is the minimal model we wished to examine, including the reflectance ratios but no other patient information. Here, the deviance decreased significantly, as would be expected knowing the earlier success of the BDI ratios in correctly classifying burns. The coefficients for this regression are listed below with their standard errors.

i th Variable	Estimate of β_i	S.E. of β_i
grand mean, G.M.	-7.22	1.006
R/IR	9.25	0.92
G/IR	-5.11	0.93

If we set the probability of a site healing in 21 days equal to 0.5, and solve for R/IR in terms of G/IR, we have a discriminant line,

$$R/IR = 0.78 + 0.553(G/IR)$$

This line is shown in Figure 1. Of 569 sites, 436 are correctly classified, a success rate of 77%. This discriminant line has the advantage over an empirically-drawn line because the regression takes each point in the data set into consideration during the computation. A human observer is not able to do this and is more likely to base his discriminator only on the points in the overlapping region of the two healing classes.

On examining the results from models with patient and wound data added, one notices that none have as large an effect on the deviance as the reflectance ratios. This indicates that other terms do not appreciably increase the model's fit to the healing responses. This is not to say that these terms may not have an effect on burn healing, only that they do not have a significant effect after the reflectance data has already been included in the model. Many of the models show slight drops in the deviance as would be expected from the addition of any term due to the reduction in the number of degrees of freedom, but none indicate strong correlation with the patient response. Examination of the regression coefficients added further weight to this judgement as most had small coefficients and relatively large standard errors.

One regression model that proved interesting was the one that included the body part. In the study, burn sites were grouped into six location categories and the regression coefficients are shown below:

Variable, i	Estimate of β_i	S.E. of β_i
with head and neck:		
G.M.	-7.136	1.162
R/IR	10.7	1.10
G/IR	-5.80	1.10
with: arms	-1.727	0.429
abdomen, chest	-0.576	0.495
back	-0.807	0.495
legs	-1.482	0.441
hands, feet	-1.595	0.453

One sees that head and neck sites (the category for which the grand mean, R/IR, and G/IR coefficients are calculated) have a slightly greater probability of healing in 21 days than do other body parts. This conclusion is evidenced by the negative values of β_i for these variables. This would manifest itself on a ratio plot as a slightly lower line for head and neck sites than for other wound locations, increasing the size of the region which predicts higher than 50%

probability of healing in 21 days. This difference is small and may only be due to the small sample size (only 41 head and neck sites compared with 152 for arms and 135 for legs), but could also be due to greater blood flow to the skin in the head and neck. The face and scalp are, in general, more highly perfused with blood than other skin areas and this may lead to more rapid healing for a given depth of burn. Due to the high visibility of the head and neck, surgeons are more likely to consider cosmetic results in treating such burns. Thus, in the case of a facial or neck burn, the BDI may not be as useful for burn management as it is for wounds on other parts of the body, since cosmetic issues may take precedence over the length of the hospital stay.

Conclusions

By using a logistic regression technique on the collected burn injury data, we were able to both perform a discriminant analysis on the two patient outcome groups using the reflectance data and at the same time check for possible correlation between patient and wound variables and the outcomes. A clinically useful discriminant line was found which graphically divides the reflectance ratio plot into regions of greater and less than 50% probability of healing in 21 days. By testing larger linear models which included terms representing clinical patient and wound variables (age, sex, burn location, etiology of the burn, and percentage of the body burned), and finding no appreciable increase in fit, we were able to confirm the patient independence of the device. The BDI's measurements were independent of patient and wound types tested in predicting time to healing and one discriminant line is probably applicable to all burns. This indicates that further research into the BDI's performance should focus on the optical characteristics of the burn wound and its optical characteristics in attempting to explain and avoid burn misclassifications. Our present research is directed toward examining excised eschar for transmittance and reflectance in different spectral regions. This may help explain the BDI's predictive ability and lead to a model describing the optical characteristics of thermally injured skin and its changes with burn depth.

Part II: The Doppler Ultrasound Skin Blood Flow Instrument

Although the electro-optic burn depth instrument has been proven to be of value in estimating the "time to healing" of major burns which are otherwise difficult to assess, the Doppler ultrasound skin blood flow technique offers the potential of an even more useful clinical tool. For example:

- 1) The technique is usable in burn wounds whose surface is not prepared in a standard manner (e.g., freshly debrided, with no anti-bacterial creams applied).
- 2) The technique measures a physiologically-important parameter directly, whereas the BDI measures an integrated effect of the light scattering characteristics of the tissue.
- 3) The ultrasound technique may be used to assess wound healing in cases other than burns.

The following sections describe our research efforts devoted to the development of the ultrasound technique.

Introduction

Skin blood flow is an important parameter in a number of physiological processes, including healing of wounds due to burn injuries or other injuries, skin diseases, thermal regulation, skin nutrition, and so on. A number of methods have been developed in an attempt to quantify this parameter: radio-active isotope clearance [2], plethysmography [3], and laser Doppler [4-7] to name a few. Of these methods, the laser Doppler instrument is the simplest to use and has the benefit of being noninvasive. In this report a new method of skin blood flow measurement using pulsed Doppler ultrasound is discussed. Our research indicates that parameters relating to skin blood flow appear in the output of a Doppler ultrasound flow detector.

Our research has been aimed at identifying unique Doppler flow patterns at specific depths in the skin, and correlating these patterns with the vessel structure at that depth. Since the ultrasonic wave speed in tissue is approximately 1500 m/sec, the ultrasound Doppler instrument can open its receiver gate at a selectable delay with respect to the transmitted burst, thus allowing scattered signals from varying depths to be distinguished. This feature contrasts with the limitation of the laser Doppler instrument which, due to the speed of light, must operate in a continuous wave mode, and thus reflections from different depths cannot be distinguished. A Doppler ultrasound instrument possessing the capability to identify structures at different depths in the skin could conceivably be of use in evaluating the depth of skin damage due to a burn injury.

The instrument used in all investigations is a 20 MHz pulsed Doppler ultrasound flow detector [8], with a depth resolution of about 0.3 mm. The major feature of this instrument is the ability to eliminate small amplitude, relative motion artifacts between the transducer and the skin. This is accomplished by initiating both the clock phase and receiver gate delay circuitry by the first received reflection (skin surface) after the transmit burst. Thus, when the skin surface moves with respect to the transducer because of plethysmographic effects or muscle tremors beneath the skin, the reference point for the clock phase and the receiver gate also moves, and thus the receiver gate always stays at the same depth in the skin. Therefore, only motion relative to the skin surface should give Doppler shifted frequency components in the ultrasound output. Blood cells, vessel walls and interfaces within the skin will all give Doppler components in the output, since their motion may not follow the motion of the skin surface (stratum corneum).

In all the investigations presented here, the audio output of the ultrasound device was tape recorded with a bandwidth of 0 to 312 Hz on an HP306A FM instrumentation recorder. The power spectrum of the recorded data was observed using a Bruel and Kjaer high resolution signal analyzer, model 2033.

New Transducer Design

A new ultrasound transducer was designed and constructed to enable us to take data on a wide range of body sites. Another criterion was that the new transducer had to be acceptable for use in the Burn Center at Harborview. Thus, attention had to be paid to eliminating the chances of transmitting infectious

agents between patients. Figure 2 illustrates the new transducer design. A cylindrically-shaped aluminum block forms the body of the transducer, and contains the ceramic crystal which generates and receives the ultrasound signal. Since 20 MHz sound waves are not transmitted through air, the ceramic crystal is in contact with a column of water, which transmits the acoustic waves with little attenuation. The water column and transducer body are separated from the skin of the patient with a thin latex membrane, approximately 0.001" in thickness, which is held in place on the transducer body with an O-ring. This membrane is the only part of the transducer body to touch the patient, and it is replaced before measurements are made on each successive subject. In addition, the transducer and its attached wires will be immersed in a sterilizing solution before and after each use.

A small amount of sterile gel couples the ultrasound transducer to the skin of the subject. The transducer may be taped to the skin of the subject for extended studies, or may be held in place with gentle pressure for the normal observation time of less than one minute.

Studies on Normal Subjects

The objectives of this series of experiments were:

- 1) To record and analyze ultrasound Doppler skin blood flow spectra from normal skin at several body sites. These sites included the forearm, upper back, abdomen, and leg.
- 2) To observe the changes in the Doppler spectra that result from heating the skin.
- 3) To study the Doppler spectra as a function of depth in the skin, from 0.3 mm to below the dermal-subcutis interface, with a depth resolution of 0.3 mm.

All studies were performed on a 25 year old male volunteer. The sites were heated by the application of a hot water bottle. Figure 3 shows a typical spectral series from one of the sites.

In general, at skin depths appropriate to the capillary bed, the amplitude of the Doppler spectra corresponding to blood flow velocities below 1.5 mm/sec increased when heat was applied to the skin site. However, reproducibility of data from hour to hour at the same site, held at what appeared to be similar conditions, was very poor. This fact prevented us from detecting major trends, or making any unique characterizations of the spectra from different sites and different depths. We were, in fact, struck by the large variability of blood flow signals.

Another problem was caused by the sensitivity of the Doppler spectrum to the motion of skin structures other than blood cells. Muscle twitch, though barely perceptible, would cause a hundred-fold increase in Doppler signal amplitude. These noise signals had to be excluded from our measurements, which proved to be difficult.

Comparison of Ultrasound and Laser Doppler Instruments

In order to assure ourselves that the variation in blood flow signals that we were observing with our ultrasound Doppler instrument was not merely caused by instrumental effects, we conducted a series of simultaneous measurements of contiguous skin sites using our instrument and a Laser Doppler instrument borrowed from Dr. G. Allen Holloway, Center for Bioengineering. Two sites were chosen, the upper back and the forearm, and on both, the ultrasound and laser Doppler transducers were affixed within two centimeters of each other. The output of the laser Doppler instrument consists of the integrated amplitudes of all the high frequency Doppler signals generated within the volume of tissue illuminated by the laser beam (approximately a sphere with 1 mm radius). The ultrasound instrument, on the other hand, recorded the details of the Doppler spectra at several different skin depths, ranging from 0.3 to 2.4 mm.

The tests were conducted by first obtaining a baseline reading with the two instruments measuring the blood flow in skin at normal temperatures. Then, the chosen site was heated with a hot water bottle, and the skin blood flow was measured again. These measurements were continued until the blood flow returned to baseline values once again.

In measurements with the laser Doppler on both sites, the blood flow signal increased sharply over the baseline value when the skin was heated, and returned slowly, with an oscillating component, to the baseline value after the skin was permitted to cool down. The measurements with the ultrasound instrument indicated that the enhanced blood flow occurred only at certain depths in the skin, and at these depths, there was a good correlation of results between the laser and ultrasound Doppler instruments. At other skin depth settings, however, no appreciable change in blood flow was recorded by the ultrasound unit. For example, on the forearm, enhanced blood flow was measured within approximately 0.75 mm of the surface. On the back, however, the enhancement of blood flow was detected between 0.75 and 1.5 mm below the surface. The more superficial layers showed no change with heating. This result may be explained because the skin on the back is much thicker than forearm skin, and the capillary bed of the former is situated deeper in the skin. These results confirm the fact that the ultrasound skin blood flow instrument can differentiate blood flow patterns as a function of depth in the skin.

We also learned that the blood flow to localized skin sites exhibits significant variation in perfusion from time to time, even though the external conditions appear to be stable. This has been noticed with the laser Doppler instrument for several years, and it explains the variability of blood flow signals that we were measuring with our unit.

Protocol for Measurement of Burn Wounds

Based upon the development of the new ultrasound transducer, and our experience with the ultrasound unit in measuring blood flow in normal skin, we plan to begin to acquire data on selected burns on patients in the Burn Center, Harborview Medical Center. The protocol calls for the selection of patients whose burns preserve a normal contralateral skin site on which similar measurements will be made for comparison. In addition, the skin temperature of the patient at the measurement sites will be monitored and data will be taken only after thermal stability is attained.

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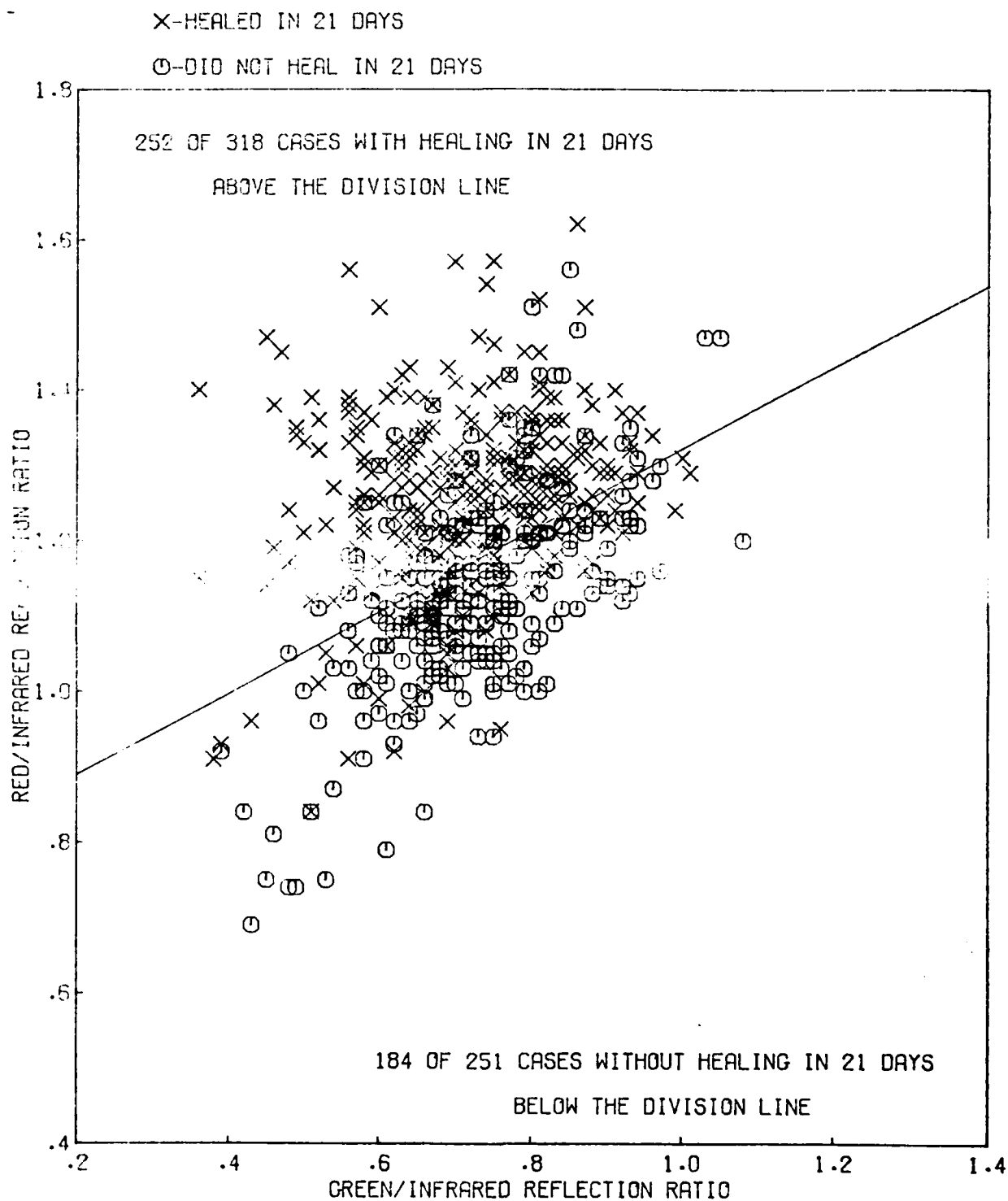


FIGURE 1

Ultrasound Transducer

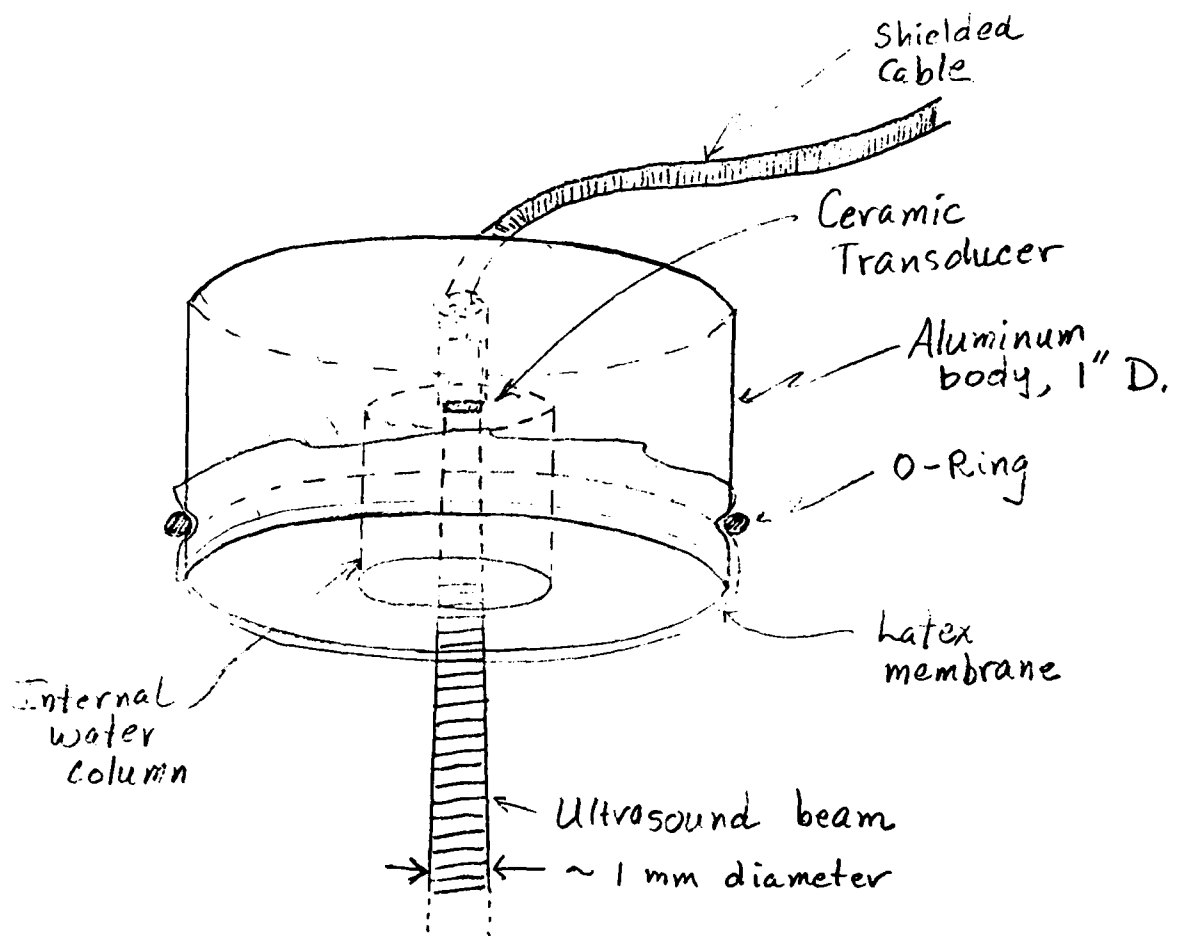


Figure 2.

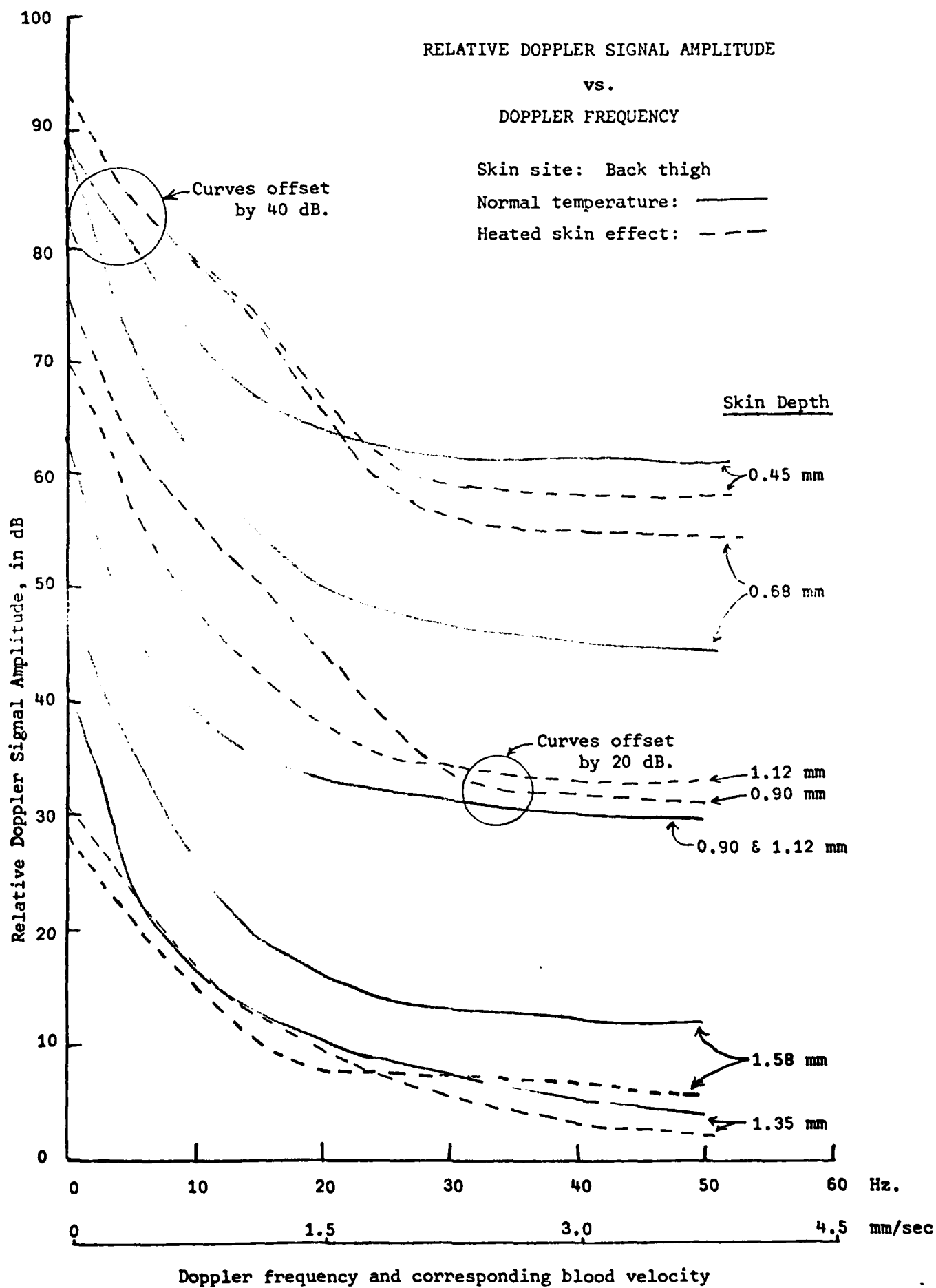


FIGURE 3

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